

University of Groningen

Virtal-photon capture in the three-nucleon system

Garderen, Elsa Diane van

IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.

Document Version

Publisher's PDF, also known as Version of record

Publication date:

2006

[Link to publication in University of Groningen/UMCG research database](#)

Citation for published version (APA):

Garderen, E. D. V. (2006). *Virtal-photon capture in the three-nucleon system*. s.n.

Copyright

Other than for strictly personal use, it is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license (like Creative Commons).

The publication may also be distributed here under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license. More information can be found on the University of Groningen website: <https://www.rug.nl/library/open-access/self-archiving-pure/taverne-amendment>.

Take-down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Downloaded from the University of Groningen/UMCG research database (Pure): <http://www.rug.nl/research/portal>. For technical reasons the number of authors shown on this cover page is limited to 10 maximum.

Virtual-Photon Capture in the Three-Nucleon System

Elsa van Garderen

Front cover:

Norman Rockwell Saturday Evening Post Covers

September 2, 1939 - *Marble Champion*

Back cover:

Two examples of three-*nucleon* systems.

Acknowledgement:

I would like to thank John Rockwell and the Norman Rockwell Family Agency for allowing me to reproduce *Marble Champion*.

This work has been performed as part of the research program of the *Stichting voor Fundamenteel Onderzoek der Materie* (FOM), which is financially supported by the *Nederlandse Organisatie voor Wetenschappelijk Onderzoek* (NWO).

RIJKSUNIVERSITEIT GRONINGEN

Virtual-Photon Capture in the Three-Nucleon System

Proefschrift

ter verkrijging van het doctoraat in de
Wiskunde en Natuurwetenschappen
aan de Rijksuniversiteit Groningen
op gezag van de
Rector Magnificus, dr. F. Zwarts
in het openbaar te verdedigen op
16 juni 2006
om 13.15 uur

door

Elsa Diane van Garderen

geboren op 9 juni 1978
te Chambray-lès-Tours, Frankrijk

Promotor:

Prof. Dr. H. Löhner

Co-promotor:

Dr. J. Bacelar

Beoordelingscommissie:

Prof. Dr. R. Čaplar

Prof. Dr. G. Fäldt

Prof. Dr. Ir. R. Hoekstra

CONTENTS

1	Introduction	7
1.1	Nuclear physics and the nucleon-nucleon interaction	7
1.2	The deuteron-proton radiative capture	10
1.2.1	The real-photon capture	10
1.2.2	The virtual-photon capture	11
1.3	Outline of this thesis	12
2	The proton-deuteron radiative capture reactions	15
2.1	The models	16
2.1.1	The low energy theorem	17
2.1.2	The covariant impulse approximation and the relativistic gauge-invariant model	17
2.1.3	The charge-dependent CD-Bonn potential model	19
2.2	Real-photon capture reaction	20
2.3	Virtual-photon capture reaction	22
2.3.1	The $pd \rightarrow {}^3\text{He } e^+e^-$ amplitude	23
2.3.2	The $pd \rightarrow {}^3\text{He } e^+e^-$ cross section and response functions .	24
2.3.3	Comparison of the two models in the case of the virtual- photon capture	27
3	Monte Carlo modeling	29
3.1	Monte Carlo event generator	31
3.2	Phase-space weighting	34
3.3	Phase-space and matrix elements	34
3.4	Monte Carlo errors	35

3.5	Implementation of the model	36
3.6	Comparison of the simulation to the theory	36
4	Experimental setup	39
4.1	AGOR cyclotron and the ion sources	40
4.2	Liquid hydrogen target	43
4.3	The Big Bite Spectrometer	43
4.3.1	EuroSuperNova	45
4.3.2	Electronics scheme	47
4.4	The Plastic Ball	47
4.4.1	Scintillators	48
4.4.2	Electronic scheme	49
4.5	Coincidences between Plastic Ball and the BBS	52
4.6	Kinematics	53
5	Event selection	55
5.1	Data stream, data acquisition and online monitoring	56
5.2	Identification of ^3He , photons and leptons	57
5.2.1	Identification of ^3He	57
5.2.2	Identification of photons and leptons	59
5.3	Methodology of the analysis	62
5.3.1	Real-photon capture	62
5.3.2	Virtual-photon capture	63
5.4	Corrections applied to the data	69
5.4.1	Efficiency	69
5.4.2	Acceptance	71
6	Analysis and comparison to theory	75
6.1	Expression for the cross section and the response functions	76
6.1.1	Cross section	76
6.1.2	Response functions	77
6.2	Real-photon capture: $p + d \rightarrow ^3\text{He} + \gamma$	79
6.3	Virtual-photon capture: $p + d \rightarrow ^3\text{He} + e^+e^-$	82
6.3.1	Cross section of the virtual-photon reaction	82
6.3.2	Response functions	83
6.4	Conclusion on the analysis	90

7	Summary, conclusions and outlook	93
7.1	Summary	93
7.2	Conclusions	95
7.2.1	Real-photon capture	96
7.2.2	Virtual-photon capture	96
7.2.3	Conclusions on the theoretical models	97
7.3	Outlook	97
A	Improvement of the setup	99
A.1	The Čerenkov inner shell	99
A.2	The CsI inner shell	101
B	Nederlandse samenvatting	103
	Kernfysica en de nucleon-nucleoninteractie	103
	Experiment: deuteron-proton vangstreactie	105
	Resultaten	107
	Dankwoord - Acknowledgment	111
	Bibliography	113

